Equipment Development & Test Report
No. 7700-10
September 1976

development of the Forest Service TRAIL TRAFFIC COUNTER

U.S. Department of Agriculture - Forest Service
Equipment Development Center
Missoula, Montana

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Development of the Forest Service Trail Traffic Counter

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Abstract

By the mid-sixties, growing recreational use of public lands spurred a search for a device to accurately count trail traffic. The Missoula Equipment Development Center investigated and field tested a number of traffic counters developed by private firms. All failed to meet one or more of the performance criteria identified in a Servicewide survey. As a result, a Center engineer designed circuitry tailored to Forest Service trail traffic counting needs, and a commercial contract was awarded to produce counters in quantity.

The final product is a lightweight, easy-to-conceal counter that operates under all weather conditions for 2 to 3 months on a set of dry cell batteries. The counter produces a beam of infrared light that monitors trail traffic. When an object interrupts that beam an impulse counter advances one digit. Timing circuits make the counter immune to triggering by falling leaves, flying birds, and other such phenomena, insuring accurate counts. The counter is on the Federal Supply Schedule and can be purchased directly from the manufacturer, Scientific Dimensions, Inc., Albuquerque, N. Mex.

Theory of operation and installation procedures are explained. An appendix contains a detailed account of the search for a counter.

Key words: Trail traffic counter; trails; recreation management; recreation use; equipment engineering; equipment testing.

A report on Equipment Development and Test Project 1977, Trail Traffic Counters, sponsored by the Divisions of Engineering and Recreation.

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Need for a Trail Traffic Counter

Equipment Development and Test (ED&T) Project 1977, Trail Traffic Counters, began in 1968 when it became evident that better trail surveillance methods were needed to assess the growing impact of recreation on Forest Service lands and to aid in developing a better trail maintenance and construction program. Complicating the task was the fact that today's recreationists are not only hikers or horsemen, but they also travel the forests on a variety of machines – snowmobiles, trail bikes, all-terrain vehicles. It would take a fairly sophisticated instrument to accurately tally such an assortment of traffic.

In the sixties, except for manual tallying, the only methods for counting traffic on trails were photoelectric vacuum tube circuits and pneumatic pads. Manual tallies were prohibitively expensive and not always reliable; vacuum tube circuitry required large amounts of electrical power, an impossibility at remote sites; and pneumatic pads buried in trails were easily damaged and grossly inaccurate.

Improved trail traffic counting was a recognized need throughout the Forest Service. Louis Felton, a Forest Service technician, submitted an employee suggestion for a counter that was an adaptation of a security device, the ultrasonic intrusion alarm.

The Felton counter consisted of a transmitter and receiver (fig. 1). The transmitter directed a beam of ultrasonic energy across a trail to the receiver. When an object passed, the receiver detected changes in the beam's intensity and recorded a count. To assess the potential of this concept, 20 units were tested in the field for a summer. Serious deficiencies in performance and battery failures occurred.

We found that when air between the transmitter and receiver was moving, even in a light breeze, the phase relationship of the ultrasonic beams changed. The receiver interpreted this as trail traffic, and spurious counting occurred. If air moved fast enough, it could actually sweep the beam away from the receiver causing thousands of counts per hour that quickly exhausted the batteries. For this reason, we abandoned the concept of ultrasonic energy.

Meanwhile, burgeoning semiconductor technology had advanced solid state optoelectronics, and new devices such as solid state infrared light-emitting diodes and photosensitive transistors emerged. We felt a beam of infrared light might be used to monitor trails. A counter could be designed that would tally interruptions in the beam caused by objects passing along the trail.

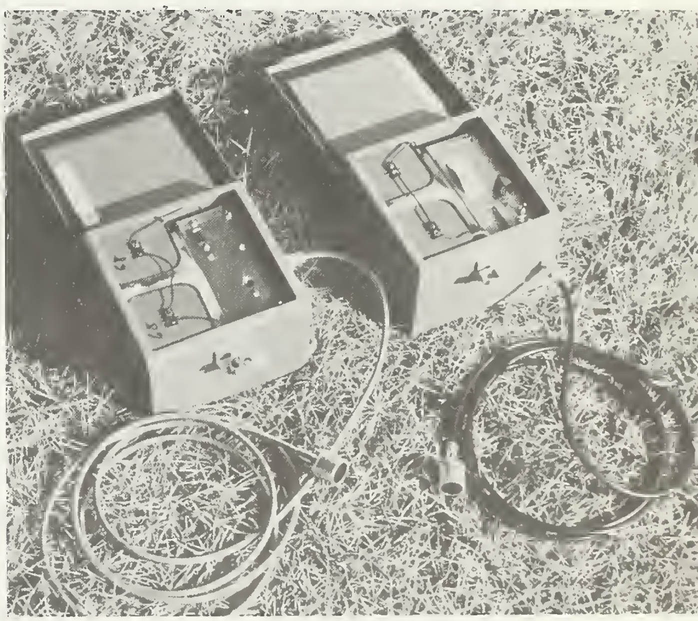

Figure 1. – Felton counter consisting of transmitter (left) and receiver.

But before development could begin, we had to find out what performance features a counter should have. Forest Service units throughout the country were surveyed in January, February, and March 1968. Results showed that a counter must:

- Be easily hidden to avoid vandalism.
- Be lightweight and portable.
- Operate 30 days without maintenance.
- Record cumulative count.
- Cost less than $250.
- Function under all weather conditions, in daylight or darkness, and in temperatures from -30°F to +120°F.
- Be highly reliable and accurate.

In July 1968, we launched our counter project with two goals in mind: Find a commercial product to meet these performance features and determine the best way to detect and count a unit of trail traffic.

Although the Felton concept had proved unworkable, it did furnish the impetus to begin a search for a better method of counting trail traffic.

Counter Development

Initially, we looked for a commercial infrared counting device that might be adapted to Forest Service needs. A number of counters were investigated and field tested. But all failed to meet one or more of the Forest Service criteria for a counter: They were too heavy or too costly, not accurate enough, or had a short service life.

After several such disappointments, we realized we would have to design the needed circuitry ourselves. An electronic circuit tailored to meet performance requirements for a Forest Service trail traffic counter was designed by David S. Gasvoda, a Center electronic engineer.

Gasvoda's circuitry combined the latest optoelectronic devices with the best techniques of circuit design. When installed in a single-lens housing, the Gasvoda circuit produced a beam of infrared light that could be reflected back to the counter from 50 feet away. This was twice the range of commercial counters tested and at one-fourth the power consumption rate (120 milliwatts). (Range was further increased to 75 feet in production models by using improved phototransistors in a twin-lens housing.)

Increased range and lowered power use were achieved by driving a light-emitting diode (LED) with high peak-current pulses of short duration at a rate of a few hundred pulses per second. Timing circuits controlled the frequency of these pulses. The resulting duty factor $\left(\frac{\text{on-time}}{\text{off-time + on-time}}\right)$ of 0.005, compared to 0.5 for the commercial product, accounted for the low average power use. At the same time, this duty factor enabled the circuitry to deliver very bright pulses[1] that extended range. The timing circuits also provided count and reset time constants to insure count accuracy by giving the unit the ability to reject spurious events.

[1] Brightness of the LED is a function of instantaneous driving current or power amplitude.

Since the counter now consumed less power, lightweight, disposable dry cell lantern batteries replaced the heavy lead-acid batteries used in earlier units. The dry cells could power the counter for 60 to 90 days.

Thermally compensated circuitry allowed the unit to operate unaffected by wide changes in temperature, and a feedback circuit compensated for changing light levels.

Designing the printed circuit boards began in February 1970. We fabricated test samples of the layout at the Center and assembled a counter prototype (fig. 2). Because the phototransistor and amplifier were so sensitive to signals from other parts of the counter, they had to be relocated to minimize interference with their operation. Our second prototype met all performance criteria. The design was completed and the artwork released to a manufacturer for production of 10 circuit boards. Center engineers then assembled 10 boards in commercial counter housings and delivered the units to the Forest Service's Rocky Mountain Region. We instructed personnel there in how to install, use, and maintain them.

The Gasvoda counters performed well in field trials that summer.

After developing production prototypes, a contract to produce counters containing this circuitry was awarded in April 1971 to Scientific Dimensions, Inc. (SDI), an Albuquerque, N. Mex., firm. (A detailed account of counter development can be found in appendix A.)

Figure 2. — Prototype counter with Gasvoda circuit.

Some 256 counters were purchased initially from SDI. But many other Government agencies wanted them. In view of the demand, the General Services Administration put the counter on the Federal Supply Schedule, and placed SDI under contract to produce them.

Today, hundreds of these counters are found on recreation lands throughout the United States and Canada. Besides the USDA Forest Service, agencies using them include: Bureau of Land Management, National Park Service, Army Corps of Engineers, Border Patrol, Fish and Wildlife Service; scores of State, county, and city governments, as well as Canadian Federal and Provincial agencies.

SDI now markets several versions of the counter: model TCS 90, the original counter, costs about $275; model TCS 90-1, which has a 120-foot range, sells for around $290. SDI has also redesigned and repackaged the counter for security applications. Complete information about various counter models and prices can be obtained from Scientific Dimensions, Inc., 309 McKnight, NE., Albuquerque, N. Mex. 87102; telephone 505-247-9180.

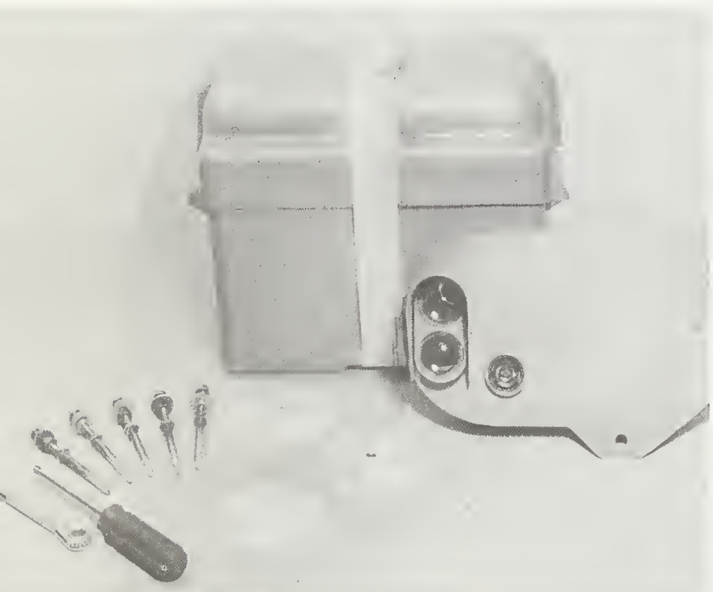

Figure 3. – Forest Service trail traffic counter.

Counter Description

The counter designed at the Center and produced by Scientific Dimensions, Inc., is lightweight, easy to conceal, resistant to false tripping, operates 2 to 3 months on a set of dry cell batteries, and functions under all weather conditions.

The counter consists of three components: Scanner, battery box, and 3-inch reflector (fig. 3).

The scanner's optoelectronic devices and associated circuitry are contained in two printed circuit boards (fig. 4). A third circuit board electrically and mechanically connects the batteries in the plastic battery box.

To prevent detection, the small scanner housing is finished in dull camouflage paint. The scanner's 75-foot range allows it to be set well away from the trail where natural camouflage can also be used. The infrared beam is invisible, and the counter cannot be heard beyond 2 or 3 feet.

The counter operates on three carbon zinc lantern batteries – two 12-volt and one 6-volt. The 6-volt battery powers a Sonalert®, an audio device used to aline the scanner's infrared beam with the reflector. The reflectors are similar to round roadside traffic control reflectors.

The electronics contained in the scanner are functionally represented by the block diagram in figure 5. The transmitter section includes a free-running astable multivibrator that oscillates at 200-250 Hz (cycles per second). The output of the multivibrator is converted to pulses by a pulse generator; the pulses, in turn, are amplified. These high-power pulses are applied to a light-emitting, gallium arsenide diode, and a transmitting lens focuses the infrared light produced by the LED on the reflector across the trail.

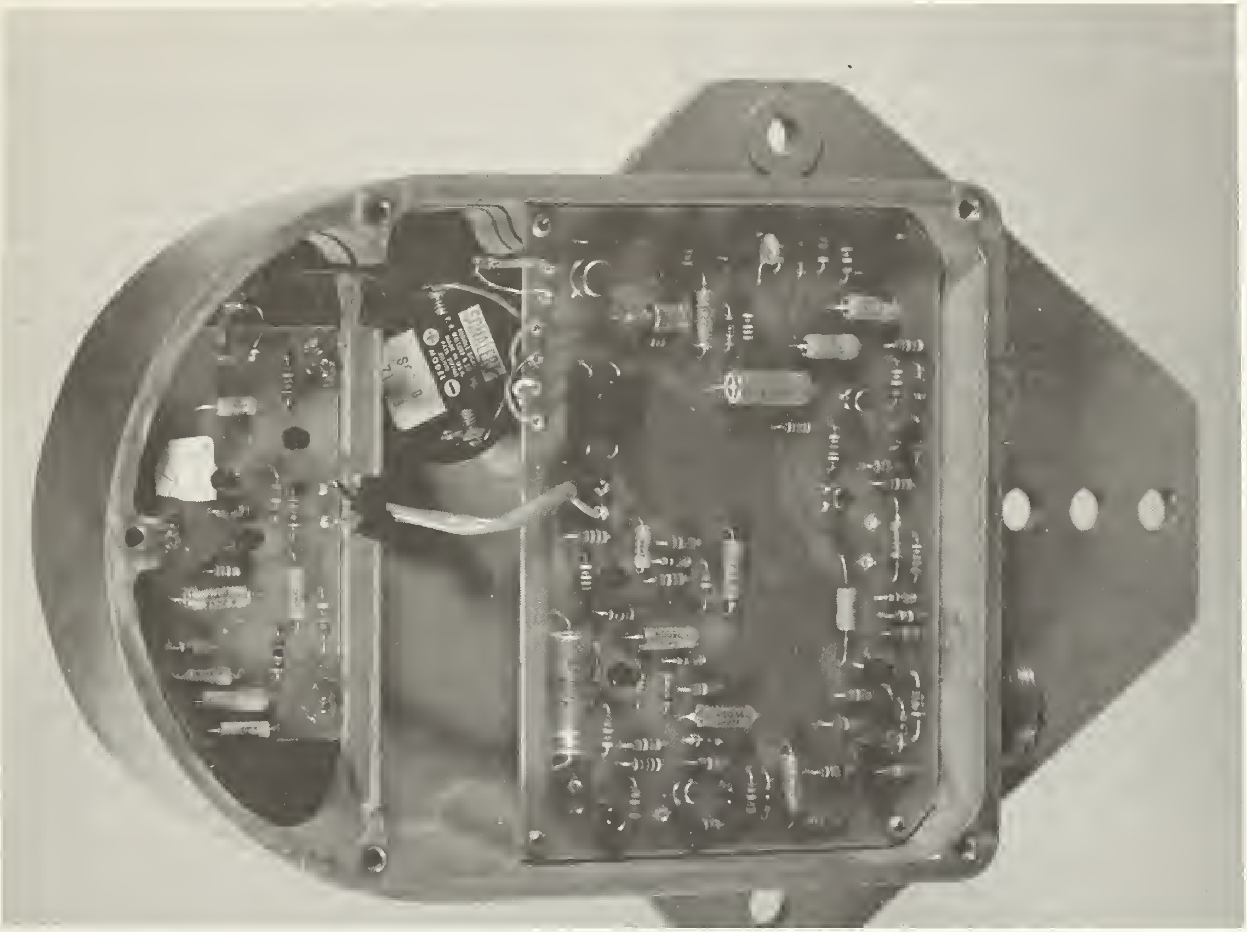

Figure 4. – Counter circuitry.

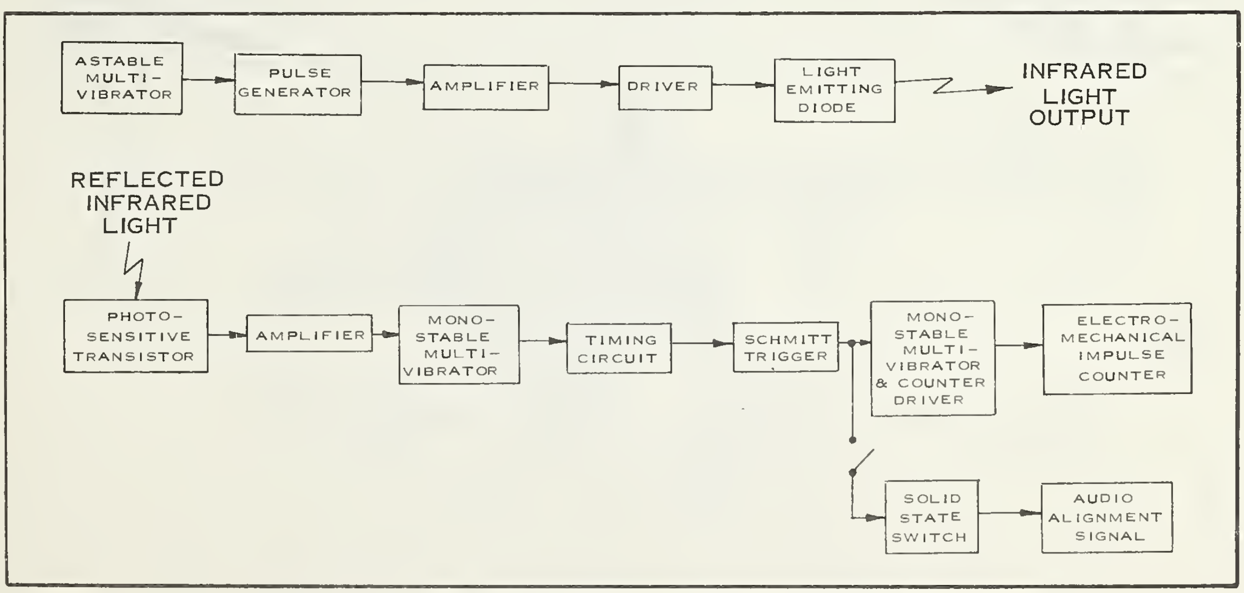

Figure 5. – Functional block diagram of scanner electronics.

The reflector returns the beam of pulsed infrared light to the scanner's receiving lens, which in turn focuses it on a photosensitive transistor. The reflected pulses are amplified, then electronically reshaped by a monostable multivibrator to eliminate noise and spurious flashes. The reshaped pulses are assessed by a time constant network and Schmitt trigger.

When an object on the trail blocks the beam depriving the scanner of a specific number of pulses, an impulse counter advances one digit. The absence of 20 pulses initiates a count, and 80 pulses must be received after the interruption to reset the circuit for the next count.

This time lag makes the counter immune to triggering by falling leaves, flying birds, snowflakes, and such. When valid traffic interrupts the pulsed beam, the count signal triggers a monostable multivibrator-driver that delivers a 42-millisecond electrical pulse to an electromechanical impulse counter, advancing it one digit.

Installation

Accurate counting depends on a proper site and careful installation.

To minimize tampering, a site should be selected where scanner and reflector can be well off the trail. A spot where trail users must pass single file and where they cannot readily detour around the counter is ideal. A "chute" constructed of brush and rocks can accomplish this. It should be kept natural looking.

It is best to avoid scenic overlooks or level areas at the top of steep grades where people tend to stop, rest, or mill around. Segments of trail heavily traveled by big game animals or range stock should also be avoided. The sight should be protected from bright sun and weather.

Figure 6 portrays a proper counter installation with scanner and reflector no more than 75 feet apart and located so that a waist-high beam sweeps across the trail at a 90-degree angle.

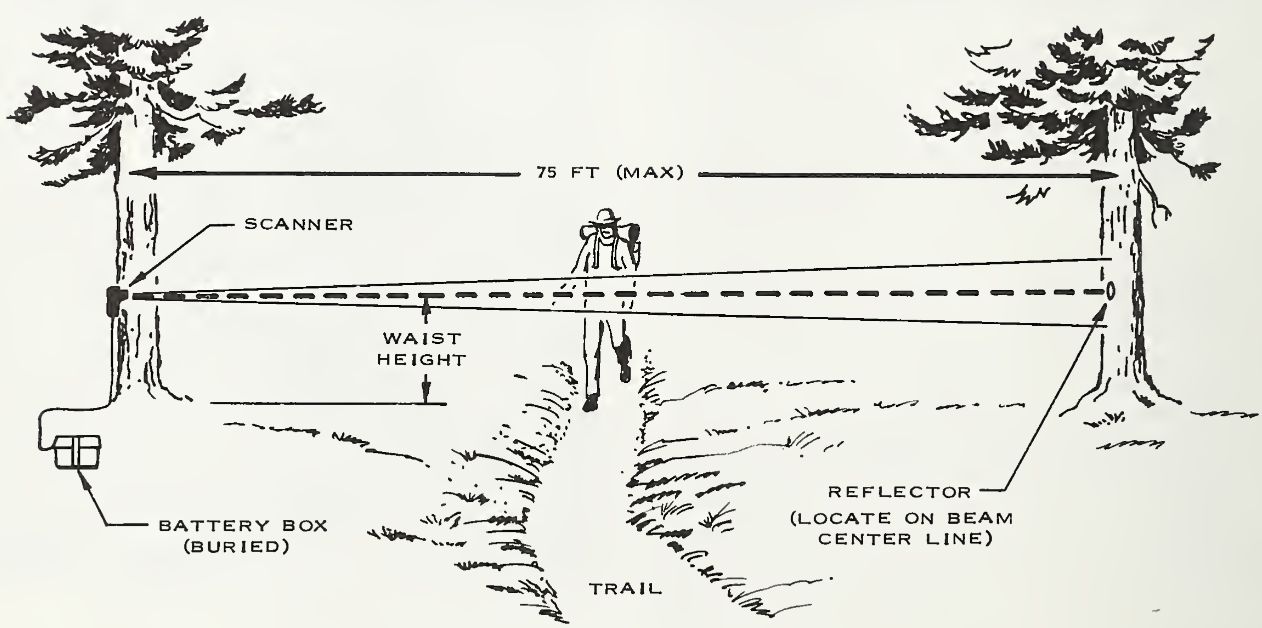

Figure 6. – Counter installation.

The scanner is mounted with three bolts (fig. 7). Since there is no "top" to the unit, it can be placed on either side of a tree or post. A string can be helpful in locating the beam's path to more easily position the reflector and to insure that no branches or brush obstruct the beam. A lens hood protects the lenses from moisture and sunlight.

Once the scanner is mounted, the power cable is connected, and the Sonalert® audio alinement device is activated by pressing the switch near the power cable socket. A tone indicates the reflector is outside the light beam. The reflector held in the beam silences the tone.

The path of the beam from the scanner is adjusted by turning the two nuts on each mounting bolt. These are turned until the center of the beam strikes the desired spot. The reflector is then fastened.

The battery box is buried, keeping the batteries at a more uniform temperature and making the installation site less obvious.

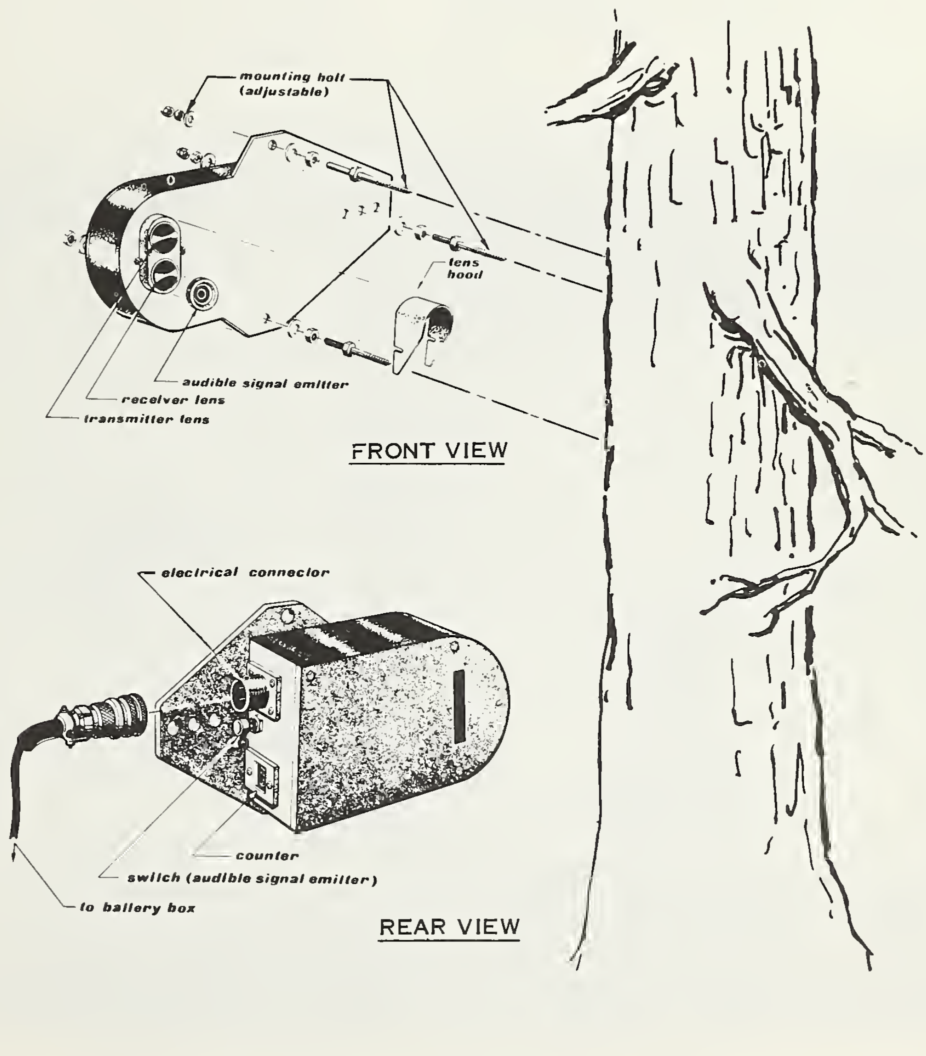

Figure 7. – Mounting the scanner.

Appendix A – Details of the Counter Search

Five years of effort went into producing the Forest Service trail traffic counter. Details of this development effort are described below.

Early Commercial Models

General Electric Co. (GE) had been applying solid state electronics principles to detection devices and showed an interest in working with us to develop a trail traffic counter.

GE provided a prototype "reflex photoelectric control" for testing. It was adapted from GE's commercial line of reflex controls for industrial applications such as counting articles on conveyor belts. The unit was installed on the Teton National Forest, Wyo., in August 1968, and returned to the Missoula Center in September for laboratory evaluation. The field trial generated enthusiasm; the unit had produced accurate data even during periods of cold and snow.

The unit consisted of a light source, a light sensor, optics for both devices, and associated electronics packaged together with an electromechanical impulse counter (fig. 8). It weighed 50 pounds and ran on 115-volt, 60 HZ power.

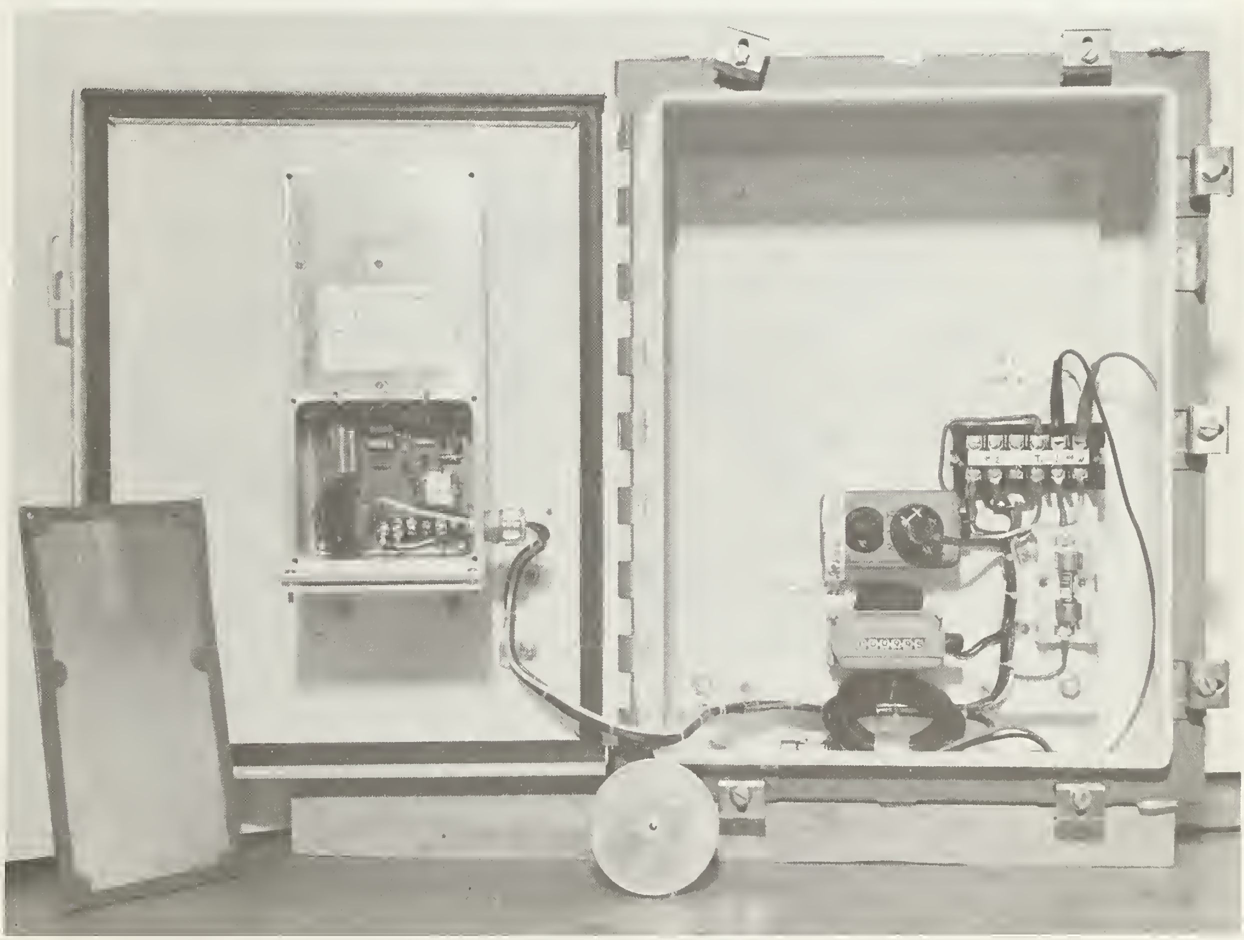

Figure 8.–General Electric's reflex photoelectric control.

The light source, a light-emitting diode, emitted a pulsed beam of infrared light through a lens in the housing. A reflector across the trail returned the light to a second lens that contained a photosensitive device. Interruptions in the reflected light were sensed by the electronics and recorded on the impulse counter. The unit consumed 1.3 watts of power at rest and 1.9 watts during a count. Maximum range was 30 feet.

Since this unit demonstrated an accuracy and reliability never before seen in trail traffic counting equipment, we hoped to convince GE to redesign its device to operate entirely on dc power, to increase its range, to reduce power consumption, and to repackage the unit in a smaller, less costly housing. Contract negotiations began in November 1968, for purchasing 20 trail traffic counters with these improvements.

A market search also was begun for alternate suppliers. In addition, we began a circuit design to familiarize ourselves with the technology, to provide proof that our requests to GE were feasible, and to provide a possible alternate course should the contract negotiations fail.

After a negotiating period in which some trade-offs of performance-versus-cost were made, we agreed to buy 20 production prototypes of GE's trail traffic counter for laboratory and field trial (fig. 9).

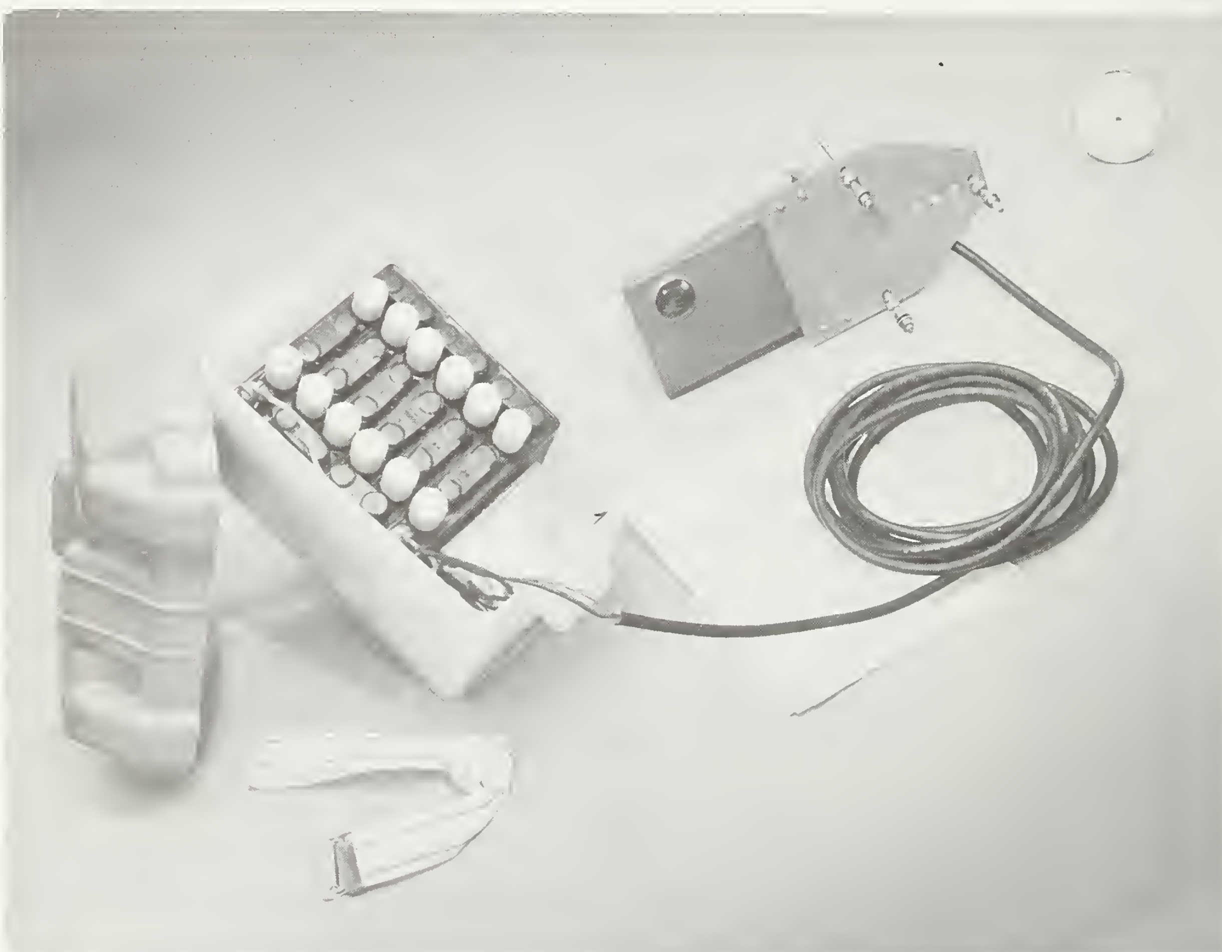

Figure 9. – GE trail traffic counter.

The new counter, repackaged in a smaller housing, had been redesigned to operate on 24-volt dc power.

The LED and the phototransistor shared a common lens. A partial mirror in the light path behind the lens directed the transmitted and received beams. This assembly, called the scanner, was connected by cable to a plastic battery box that could be buried. The battery box also held an impulse counter.

Even before we had received the 20 GE counters, our market search produced a proposal from Data Optics Corp., a small high-technology firm in Menlo Park, Calif., to adapt one of its products to Forest Service requirements. Data Optics' traffic automatic counter (TAC) (fig. 10) exceeded most of our requirements and proved to be at least 2 years ahead of development efforts at the center or GE. For this reason, work at the Center was stopped.

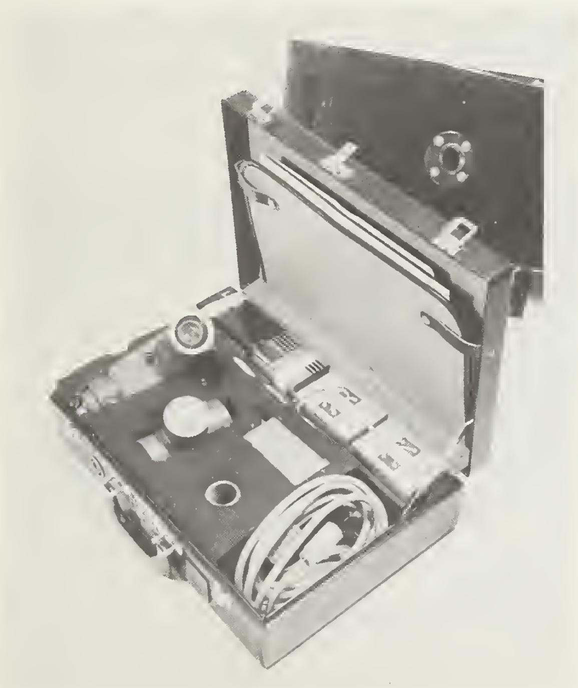

Figure 10. – Data Optics' traffic automatic counter.

The TAC contained a laser diode driven by high current, short duration pulses that produced an intense beam of infrared light. A retroreflector returned the light to a telescope lens that focused the light on a silicon photodiode. Amplifiers and logic circuits interpreted interruptions, counting valid traffic while rejecting spurious phenomena and changes in surrounding light.

The optics and electronics were housed in a plastic conduit fitting. The fitting attached to a conduit "T" which, in turn, attached to a pipe flange. With the pipe flange bolted to a tree or other solid object, adjustments made in azimuth and elevation were retained by set screws. A cable connected this unit to an attaché case containing batteries and impulse counter. The case carried all components during transit and could be placed in a plastic bag and buried when in service.

Although the TAC represented an advance in design, it used too much power and battery service life was only 15 days. Purchased in quantity, the unit cost about $1,000, four times the $ 250 limit. Solving both problems would require a much more costly redesign effort.

Prospects for a Commercial Counter Fade

In the meantime, our market search continued, and evidence mounted from field evaluations that the GE counters were inadequate. We received almost daily accounts of inaccurate counting, battery failures, and logistical problems in getting the units with their heavy lead-acid batteries to remote trail sites.

We wanted a second generation counter that would increase the range of the infrared beam so the counter could be set well away from the trail to reduce tampering and vandalism. A reduction in power consumption was needed so dry cells such as lantern batteries could replace the heavy (30 pounds) lead-acid batteries. Also, count and reset time constants should be

designed into the system to prevent spurious counts from falling leaves, arm swings, and so forth.

We were committed to delivering counters for field testing in the summer of 1970 and felt an alternate course was essential if we were to have them ready by then. We resumed our own development efforts early in the fall of 1969. The result was an electronic circuit designed by David S. Gasvoda, an electronic engineer at the Center, and tailored to meet Forest Service requirements for a trail traffic counter.

Ten counters with the Gasvoda circuit were used in the Rocky Mountain Region during the summer of 1970. They performed well in the field.

Contracting for Counter Prototypes

Even before field results were in, we circulated a formal request to develop and produce five prototypes embodying the Gasvoda circuit. The Electronics Research Laboratory (ERL), Bozeman, Mont., was selected. It is a not-for-profit corporation of the Endowment and Research Foundation at Montana State University.

A contract was awarded to ERL May 8, 1970, for the engineering design and development of the optical system and its enclosure and for fabricating five complete production prototype trail traffic counters. ERL was also to supply a complete set of production model drawings. The five units were scheduled for delivery July 1, with the drawings to follow within 6 months.

ERL's design effort led to a prototype scanner and finally to five production models (fig. 11).

The scanner held two circuit boards. A small one contained the optoelectronic devices and immediately associated circuitry and a larger board contained the remainder of the circuitry. A Sonalert®, mounted on the face of the scanner, furnished an audible signal that sounded until reflector and scanner beam were alined.

A third printed circuit board was used to electrically and mechanically connect the batteries in the plastic battery box. Three carbon zinc lantern batteries (two 12-volt, one 6-volt) powered the counter for 60 to 90 days.

The operating range easily exceeded 50 feet. All other performance features – spurious count rejection, noise immunity, temperature stability – worked as intended.

The scanner housing itself was also satisfactory. Camouflage paint, curved profile, and an invisible infrared light beam reduced the chances of visual discovery. A quiet impulse counter and the 50-foot operating range made the counter inaudible even under quiet conditions in the forest. The scanner housing fitted snugly in the battery box when not in use, along with the cord, spare reflectors, mounting bolts, and tools. Total weight, including batteries, was 20 pounds.

Three units were sent to the field for trial, and the other two were retained at the Center for demonstration and further laboratory testing.

Since ED&T 1977 project goals had been met, our effort was redirected toward a quantity purchase of counters for Servicewide use.

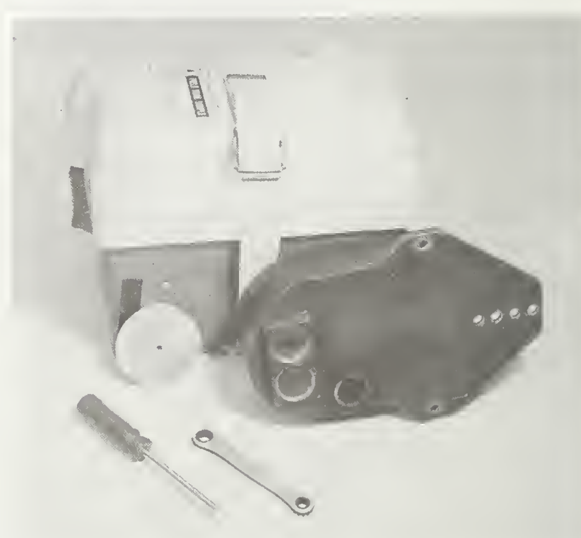

Figure 11. – Electronics Research Laboratory's production prototype.

Production Models

We began preparing an interim specification for counter production. It was primarily for materials and processes where we specified components and most fabrication techniques. A complete set of mechanical and electrical drawings would become a part of the specification and compliance would depend on a satisfactory demonstration before full production would be authorized. The drawings were revised to correct some design deficiencies revealed by field and laboratory tests of the five ERL prototypes.

Since the contract would exceed $10,000, it was advertised in the *Commerce Business Daily* the first week of February 1971, and a bidders list of 31 companies was compiled.

For the benefit of interested bidders, we demonstrated the prototype and explained the specification at a March 3 meeting at the Center. Bidding opened March 26, and 29 bids were received, ranging from $133.50 to $420 for each counter. Low bidder was Scientific Dimensions, Inc. (SDI), Albuquerque, N. Mex. A contract was awarded to SDI April 9. Our goal was to have 60 counters by August 1 for a Forest Service recreation inventory and management study.

The first article demonstration and inspection on June 1 and 2 revealed a number of deficiencies in fabrication and materials and a few errors or oversights in the drawings. Nevertheless, the first article performed well even at a range of 130 feet.

We granted SDI approval to begin producing counters once the company initiated a list of mutually agreed upon actions and improvements, including some minor drawing changes to improve the scanner housing's hermetic seal. The list was confirmed in writing, and it was agreed that the changes would be incorporated at no cost to the Government.

On July 23, SDI reported that the counters were not achieving the 90-foot operating range called for in the specification. A team from Missoula flew to the contractor's plant July 27, but the problem could not be isolated. Samples of the light-emitting diodes and the phototransistors were sent to a company specializing in optics for evaluation.

We received 60 units from SDI July 29. Of these, 20 were selected at random and subjected to the qualification inspection and test regimen of the specification. Many serious defects were noted. Five of the 12 units tested for range failed. The lot was rejected. We suspended the contract July 30 and attempted to isolate the problem.

We began a counter-by-counter search to determine why the counter wasn't achieving the 90-foot range. Exhaustive tests and measurements were made using a computer to process the data to establish a correlation with performance.

By tracing through the batch numbers stamped on phototransistors used in the ERL-produced prototypes and the devices used in the SDI production units, the source of the problem finally was identified. At some point between the production of devices for the ERL prototypes and the production of devices for SDI, the lens configuration in the photosensitive transistor was changed. In the earlier batches, the devices had a relatively wide "look angle." This meant that most of the light falling on the large lens mounted in the front of the casting was "seen" by the phototransistor. The new devices had a narrower look angle and "saw" only part of the large lens, so less light reached the semiconductor.

We needed a phototransistor with a flat window instead of a lens. Clairex, a semiconductor manufacturer, marketed such a device. Five were ordered and all demonstrated sensitivities twice as great as the other devices (fig. 12). They proved to be the breakthrough needed to resume production of the counters, and the contract was reinstated in December 1971.

Besides replacing the original phototransistors with the Clairex device, we also decided to drive the LED harder. This meant substituting one

transistor and one resistor in the lamp drive circuit. We also chose to make other improvements.

Figure 12. – Clairex phototransistor has wider "look angle" than earlier devices.

Since optical alinement was more critical than earlier thought, we devised an assembly fixture for SDI. The fixture accurately positioned the LED and phototransistor with respect to the printed circuit board. To further refine optical alinement, more machining on the casting and small printed circuit board was ordered. Machining was needed to accommodate "O" ring seals in the scanner cover plate around each screw to improve the hermetic seal. Machining was also required on the surface of the casting that interfaced with the cover to further improve the seal.

These changes required a significant amount of rework, and SDI submitted a detailed proposal for contract amendment. The proposal was incorporated into the contract, with a new delivery date of April 10, 1972, at an added cost to the Government of $25.94 per unit. SDI also agreed to draft a quality control procedure and submit it for approval. Another demonstration would be conducted using 12 samples.

On February 4, 1972, we received 12 units. Performance met or exceeded all requirements with ranges in excess of 130 feet.

The remaining 244 units arrived April 14. Thirty-two were randomly selected for inspection and testing. Only one functional defect and one visual or dimensional defect were found. The units were accepted and shipped to the offices requesting them by May 1, 1972.

Field Testing

Because of the impending widespread distribution and use of the counters, the Missoula Center designed a statistically structured accuracy and reliability test. We wanted to find out not only how accurate and reliable the counters were, but also if installation instructions in the operating manual were adequate.

Work was coordinated with the Forest Service Transportation Analysis Group at Berkeley, Calif. The initial effort was undertaken in February 1972 before the counters were sent to the field. Several test plans were drafted before one was finally selected. The test plan contained sampling methods, a mathematical formula for data analysis, and a computer program for data reduction.

We hired and trained a technician to conduct the test. At each site visited, he installed his own trail counter near the one already there, noted details of the field installation, and manually tallied and classified each unit of trail traffic and the responses of both counters to each unit.

A large amount of information was returned over the 3-month test period. The data were processed during the winter of 1972-73, and a project record, *Trail Traffic Counter Accuracy Tests,* documenting the test procedure, analysis scheme, and results was published in July 1973. In general, the test showed the counters to be extremely accurate; any inaccuracies were due to incorrect installation. Counter reliability was equally high. Only two failures were reported: one counter was vandalized, and in another, an alinement signal switch failed. To insure continued accuracy, SDI agreed to maintain a facility for repairing and refurbishing counters at owner's expense.

Appendix B – Theory of Operation[1]

The frequency source of the transmitter section is the free-running astable multivibrator (Q11 and Q12) (fig. 13). The output of the multivibrator at the collector of Q11 is a symmetrical square wave (fig. 14).

The positive going transitions of the multivibrator are applied to the gate of the field-effect transistor pulse generator (Q13) which shapes the pulses and provides isolation for the multivibrator. Figures 15 and 16 show input and output waveforms for this stage.

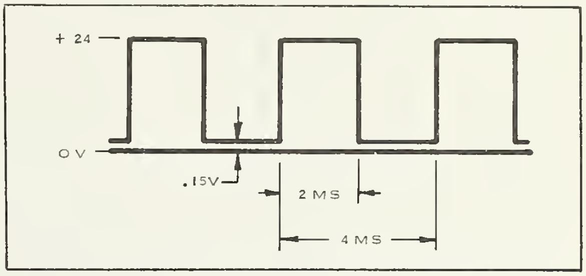

Figure 14.—Collector of transistor Q11.

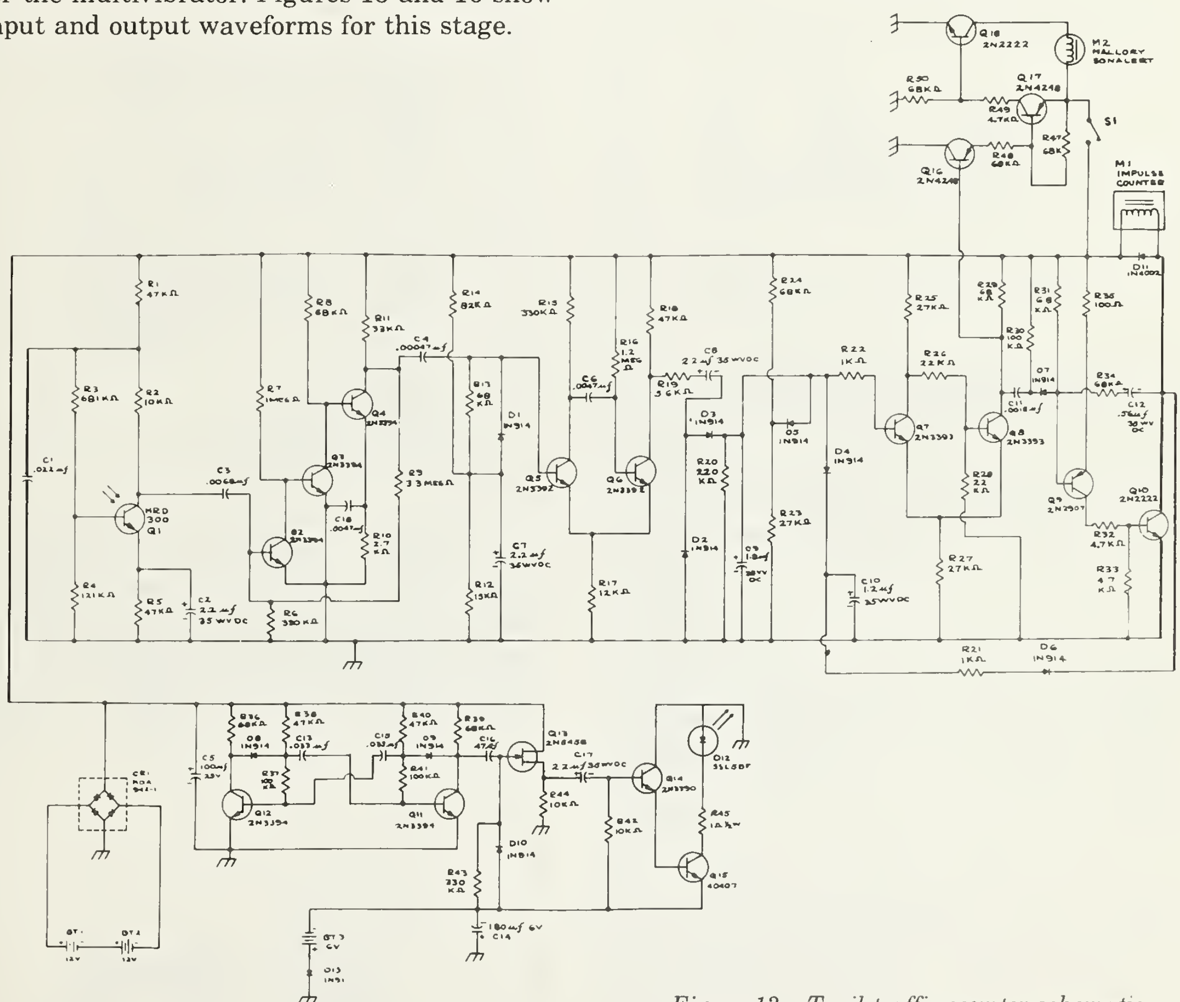

Figure 13.—Trail traffic counter schematic.

[1] The values given for voltages and time constants in this discussion represent typical values for the circuit as designed. These values may vary slightly from one production unit to another. All measurements were made with respect to ground, unless otherwise indicated, using a Tektronix type 549 oscilloscope with a type 1A1 plug-in unit and 10X, 7 pf, 10 M ohm probe.

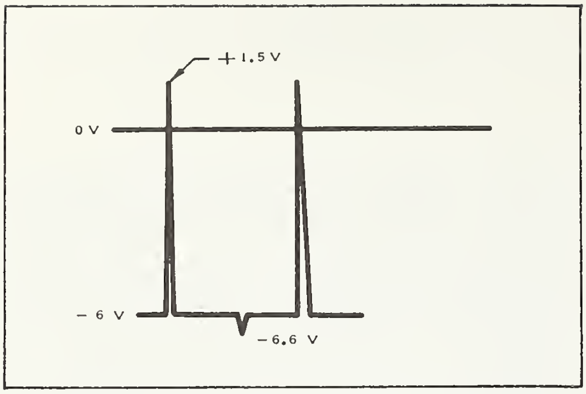

Figure 15.—Gate of transistor Q13.

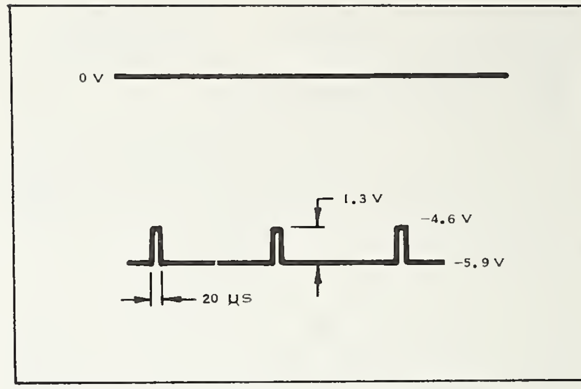

Figure 17.—Emitter of transistor Q14.

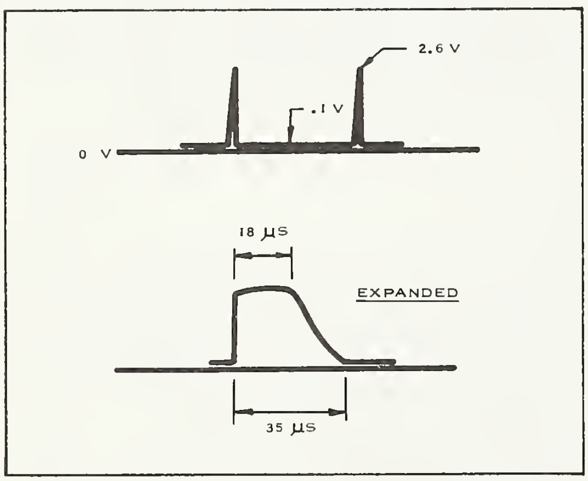

Figure 16.—Source of transistor Q13.

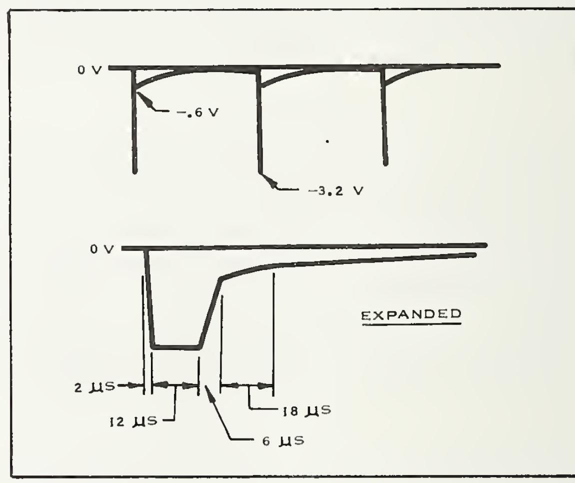

Figure 18.—Collector of transistor Q15.

The pulses are capacitively coupled to the pulse amplifier (Q14). The amplified pulses appearing at the emitter of Q14 (fig. 17) are directly coupled to the base of the driver (Q15). The output of the driver at the collector of Q15 (fig. 18) is a greatly amplified pulse that drives the light-emitting diode (D12). Figure 19 presents the waveform of the voltage across resistor R45, which is directly proportional to the waveform of the current energizing the LED. To conserve power and maximize range, the transmitter circuitry generates high power pulses of 20 microsecond duration at a rate of 250 pulses per second.

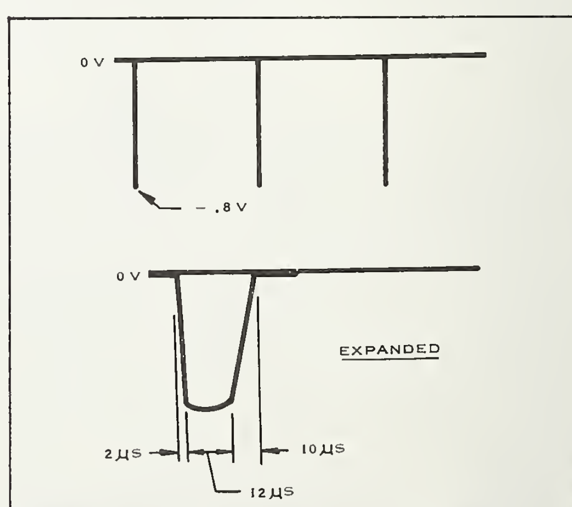

Figure 19.—Voltage across R45 (negative lead on lamp, positive lead to collector).

Reflected infrared light pulses impinging on the photosensitive transistor (Q1) are converted to electrical pulses. Figure 20 shows the waveform of these pulses as they appear at the collector of Q1 under strong signal conditions. One pulse is shown as seen with time and voltage scales expanded. When no surrounding light or infrared light pulses impinge on Q1 the collector is at 20 volts dc, and the emitter is at 2.6 volts dc.

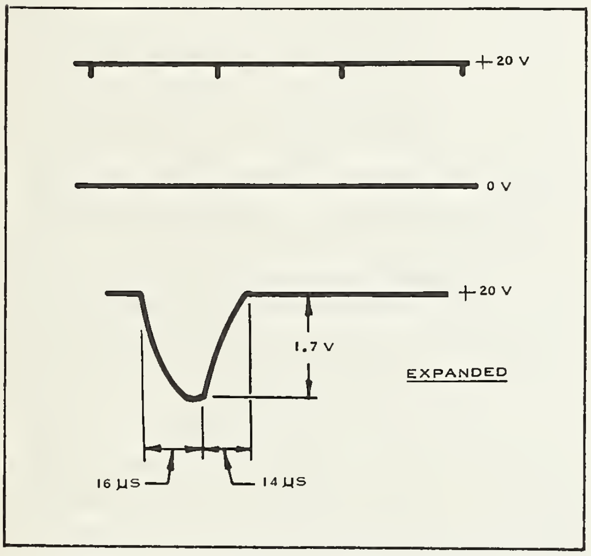

Figure 20.–Collector of phototransistor Q1.

The signal is capacitively coupled to a three-stage, common emitter, direct-coupled amplifier (Q2, Q3, and Q4). The output of the amplifier appearing at the collector of Q4 is shown in figure 21 under strong signal conditions. Without signals, the output is 8.2 volts dc with 0.4 volt peak-to-peak noise.

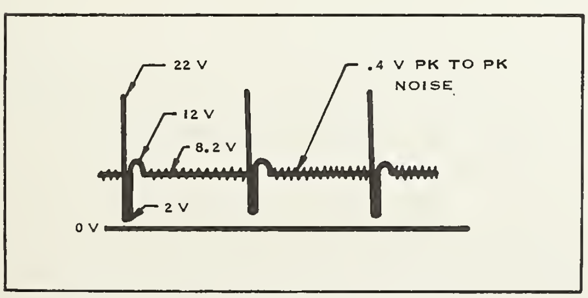

Figure 21.–Collector of transistor Q4.

The amplifier output is capacitively coupled to an emitter-coupled monostable multivibrator (Q5 and Q6). Diode D1 suppresses negative-going spikes resulting in the waveform of figure 22 at the base of Q5, for strong signal conditions. The quiescent condition at the base of Q5 is 3.7 volts dc with 0.4 volt peak-to-peak noise. Q5 is triggered into conduction by the initial pulse (minimum trigger voltage is 7.2 volts). This causes the collector voltage to fall, discharging C6 toward zero, cutting off Q6. With Q6 cut off, the emitter voltage (across R17) of the pair falls, biasing Q5 to a point in the forward active region, determined by the bias conditions set for Q5.

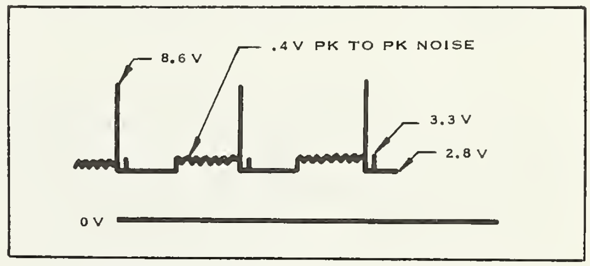

Figure 22.–Base of transistor Q5.

The transition to the quasi-stable state (Q5 on, Q6 off) takes place almost instantly. The multivibrator remains in this state until Q6 is recharged (through R18) to the point at which Q6 becomes forward biased. At this point Q6 conducts causing the emitter voltage to rise, which reverse biases Q5, driving it into cutoff. Q6 then is quickly driven into saturation; the circuit remains in this stable state until the next pulse arrives at the base of Q5. The strong signal output waveform appearing at the collector of Q6 is shown in figure 23. The quiescent condition output is 5 volts dc.

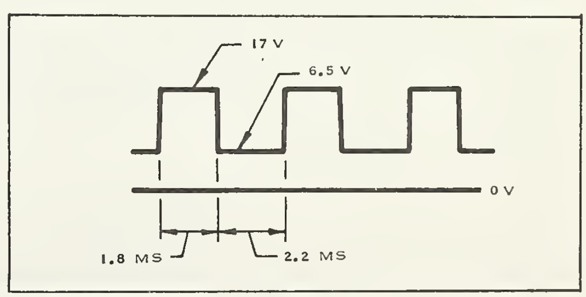

Figure 23.–Collector of transistor Q6.

The pulses, having been converted by the multivibrator (Q5 and Q6) into uniform square waves of a known magnitude and duration, are applied to the timing network (D2, D3, D4, D5, and the associated resistors and capacitors). The timing network converts the square wave into a dc voltage that is proportional to the number of transistions of the multivibrator per unit of time. That is, when light pulses are being received, the multivibrator output is steady, and the voltage at the junction of D3, R20, C9, D4, D5, and R22 is 7.6 volts dc. If the light beam is interrupted, the multivibrator stops and the voltage at the junction begins to fall at the selected rate. The minimum (quiescent condition) voltage at this junction is 0.01 volt dc.

Transistors Q7 and Q8 form a Schmitt trigger that is like a voltage-sensitive switch. The voltage developed at the junction of the timing network couples to the base of Q7 through R22. When light pulses are being received, Q7 is forward biased into the saturation region by the potential at its base. The collector voltage is at a low value that reverse biases Q8 by way of R26, holding Q8 at cutoff. The collector of Q8 and C11 are, therefore, at supply potential.

When the light beam is interrupted the voltage at the base of Q7 falls. If the beam is interrupted for 90 milliseconds (the minimum interrupt time selected to result in a count) the potential at the base of Q7 falls to 6 volts and begins to reverse bias Q7. This causes the collector voltage to increase, emitter current to decrease, and the potential across resistor R27 to decrease. Simultaneously, the increasing voltage at the collector of Q7 is coupled to the base of Q8, driving it positive; the decreasing voltage across R27 causes the emitter of Q8 to go more negative. Both actions quickly forward bias Q8 into saturation. The output at the collector of Q8 is a sharply falling potential, dropping from 24 volts dc to 7.6 volts dc when the Schmitt trigger toggles.

Upon resumption of the light beam, the potential at the junction of the timing network increases at a selected rate. After 360 milliseconds the potential reaches 7.2 volts where the above process reverses and the Schmitt trigger toggles back to the original state, and the output at the collector of Q8 is a rapid transition from 7.6 volts dc to 24 volts dc.

Only the negative-going transitions of the Schmitt trigger output are coupled to the base of Q9, by virtue of the functions of C11 and D7. Transistors Q9 and Q10 form a multivibrator-driver circuit that energizes the impulse counter for a limited interval (40 milliseconds) to conserve energy. Q9 is dc biased into the cutoff region which, in turn, holds Q10 at cutoff. When the Schmitt trigger initiates a count, the negative-going transition, coupled to the base of Q9, forward biases Q9 into conduction. The collector current flowing through the voltage divider (R32 and R33) forward biases Q10 into the saturation region. The voltage at the collector of Q10 falls into 0.6 volt, energizing the impulse counter and discharging C12 and C10. While C12 is recharging, the charge current through R31 and R34 holds Q9 in conduction. When the charge current falls to a low value, the voltage at the base of Q9 rises almost to supply potential, returning Q9 to the cutoff state, which also returns Q10 to cutoff. Figure 24 shows the waveform of voltage at the collector of Q10 during one count cycle.

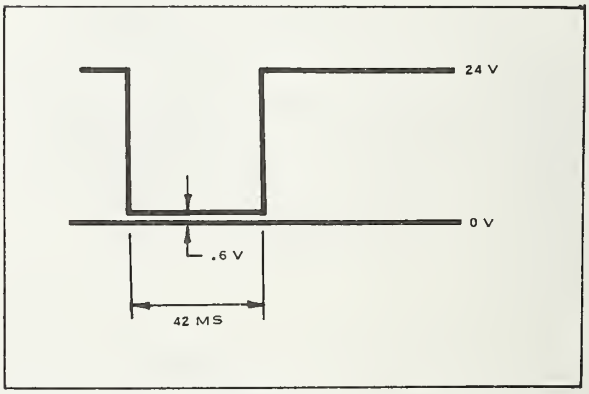

Figure 24. – Collector of transistor Q10.

The action of the feedback loop, composed of D6, R21, C10, and D4, is to hold Q7 at cutoff until the count cycle of Q9 and Q10 is completed. This sets the starting point for the reset time constant of the Schmitt trigger at zero. In this way, the Schmitt trigger will reset no sooner than 360 milliseconds after the count is initiated (or no sooner than 310 milliseconds after the light beam is reestablished and the multivibrator (Q5 and Q6) resumes operation in the case of long interruptions of the light beam). The relatively long reset time constant was selected to provide immunity to multiple counting due to arm swings of hikers, etc.

The Sonalert® alinement signal (M2) and the associated driver circuit, (Q16, Q17, and Q18) are activated by closing switch S1. When Q7 of the Schmitt trigger is at cutoff and Q8 is in saturation (as during a count or before the correct scanner-reflector alinement has been accomplished), the collector of Q8 is at 7.6 volts dc. This biases Q16 into the forward active region, which, in turn, biases Q17 into the forward active region. Q18, subsequently, is biased into saturation, thereby energizing the Sonalert®.

When light pulses are being received and Q7 is in conduction, holding Q8 at the cutoff, the voltage appearing at the base of Q16 is 24 volts dc. This reverse biases Q16 to cutoff, which results in a potential of 24 volts dc at the base of Q17. This cuts off Q17, resulting in a voltage of 0.01 volt dc at the base of Q18, which holds Q18 at cutoff, deenergizing the alinement signal.

The nominal power supply voltages are minus 6 volts dc and plus 24 volts dc, provided by one 6-volt lantern battery and two 12-volt lantern batteries connected in series, respectively. To preclude the damage that might result from incorrect installation of the batteries (CR1) a steering diode bridge was incorporated. Diode D13 was incorporated for similar reasons.

GPO 908-300

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